Size effect on flexural strength of porous concrete

M. Kunieda, T. Otono, T. Yoshida, T. Kamada & K. Rokugo
Dept. of Civil Engineering, Gifu University, Gifu, Japan

ABSTRACT: Porous concrete having continuous void of approximately 20% is one of the attractive cement based material. It has been applied to a drainage pavement and a river revetment, which requires a design based on flexural strength. There is, however, no data to discuss about size effect on flexural strength of porous concrete. This paper presents the size effect on flexural strength of porous concrete experimentally. Flexural strength of porous concrete became slightly lower with increasing of specimen depth. In this study, the size effect on flexural strength of porous concrete was as large as that of ordinary concrete. It was also revealed that the size effect due to increasing of specimen lengths was larger than that of ordinary concrete.

Keywords: porous concrete, flexural strength, size effect, void distribution, wall-effects

1 INTRODUCTION

Porous concrete is no-fines concrete having continuous voids of approximately 20% in the total volume, as shown in Fig. 1. A wide variety of applications have been proposed for porous concrete, which allows water and air to permeate through its continuous voids. The porous concrete has been applied to drainage pavements, acoustic panels, river revetments and so forth. In design of a river revetment involves structural performance, required compressive strength is higher than 16 MPa. In design of a drainage pavement, flexural strength larger than 4.5 MPa is required generally.

It is well known that the flexural strength of ordinary concrete becomes smaller with increasing of specimen size. The size effect is attributed to various causes (Bažant & Planas 1998, Carpinteri 1996), fracture mechanics size effect due to the release of stored energy of the structure into fracture front, and statistical size effect described by Weibull's weakest-link statistic etc. There are some investigations related to specimen depth including tension softening properties. The size effect also depends on specimen length, which is based on the concept of weakest link (i.e., a theory that the weakest portions within a member govern the mechanical properties of the member). Koide et al. (1997) investigated that the size effect of flexural strength regarding specimen length was large, and proposed modified statistic model.

Figure 1. Porous concrete specimen (aggregate size: 13~20mm)

The void of porous concrete, which is a sort of potential defect, is known to significantly correlate with its strength. Ando et al. (1995) revealed that the size effect on the strength of porous concrete using different specimen depths was smaller than that of ordinary concrete. Kunieda (1999) pointed out that the compressive strength of porous concrete using small specimens (100mm in diameter) leads to small values due to the effect of molded surfaces (wall-effects).

In the design of ordinary concrete members subjected to bending, consideration of the size effect on flexural strength is specified with “Standard Specification for Concrete Structures-2002, Structural Performance Verification”, i.e. the flexural strength inverses 1/4 power of the beam depth.

In the use of porous concrete, thickness of a porous concrete member is not so large (150mm or less) in a pavement and a river revetment. However, longer members with no reinforcement are applied usually.

In this study, the size effect on flexural strength of porous concrete using both different specimen

Table 1. Properties of porous concrete and used materials

Compressive strength	5~30MPa(approximately)
Void ratio	15~30% (approximately)
Cement	Ordinary Portland cement, high early strength Portland cement, blast-furnace slag cement and the like
Aggregate	Coarse aggregate: a single particle size (e.g., River revetment: 13-20 mm, Road pavement: 5-13 mm). Fine aggregate: A small amount of normal sand or fine-grained sand
Admixture	AE water reducing agent or superplasticizer (Polymer admixtures are also used to improve strength of porous concrete itself)

Figure 2. Drainage pavement (Tamai et al. 2003)

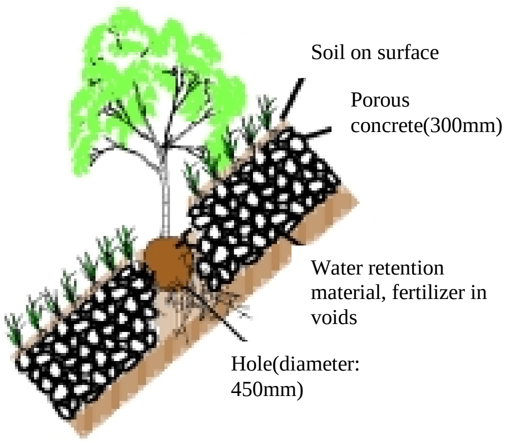

Figure 3. Image of porous concrete revetment (Tamai et al. 2003)

Figure 4. Habitat in porous concrete (Tamai et al. 2003)

Figure 5. Porous concrete basement for marine organisms (Tamai et al. 2003)

Table 2. Mix proportions of porous concrete and ordinary concrete

Series	Aggregate range (mm)	Designed void ratio(%)	W/C (%)	Unit content (kg/m^3)				
				W	C*	S	G	Ad.
Porous L	13-20	20.2	30	89.1	297	0	1609	0
Porous S	5-13	20.8	30	88.3	294	0	1583	0
Porous HS	5-13	16.8	23	71.0	316	131**	1563	6.32***
Ordinary concrete	5-13	-	63	184	293	722	1035	1.17****

* High early strength Portland cement
** Silica sand (No.7)
*** Superplasticizer
**** AE water reducing agent

depths and lengths was investigated experimentally, and was compared to that of ordinary concrete.

2 POROUS CONCRETE

Porous concrete consists of water, cement and coarse aggregate, as described in Table 1. Sometimes, a small amount of fine aggregate is used to improve the strength. Compressive strength and total void ratio of porous concrete are about 5~30MPa and 15~30%, respectively. In applications of porous concrete, to obtain both strength and void content represented by void ratio are important. In drainage pavement, higher strength is required, i.e. flexural strength higher than 4.5MPa and water permeability larger than 0.1mm/sec are required. In river revetment, not strength but void content to provide larger void to porous concrete is important.

One of the applications using porous concrete is drainage pavement, as shown in Fig. 2. Usually, smaller coarse aggregate (range: 5~13mm or smaller) is used to obtain higher mechanical properties and durability. In another applications shown in Figs 3~5, larger coarse aggregate (13~20mm or larger) is used to give larger voids, which is a space for root of plants or habitat for small organisms. Not only improving the strength of porous concrete but also controlling the void content and its size are important in porous concrete material design.

3 EXPERIMENTAL PROCEDURE

3.1 Materials

Table 2 gives the mix proportions of three types of porous concretes, as well as normal concrete. High early strength Portland cement with a density of 3.12 g/cm^3 was used for all mixtures. Porous concrete with a large coarse aggregate (porous L) having a water-cement ratio (W/C) of 30% was made using coarse aggregate with a grading and density of 13-20 mm and 2.61 g/cm^3, respectively. Porous concrete with a small coarse aggregate (porous S) having a W/C of 30% was made using coarse aggregate with a grading and density of 5-13 mm and 2.61 g/cm^3, respectively. For high strength porous concrete (porous HS), W/C was reduced to 23%, while using a coarse aggregate with a grading and density of 5-13 mm and 2.61 g/cm^3, respectively. It also contained silica sand No. 7 as a fine aggregate and a polycarboxylic type superplasticizer. In these experiments, ordinary concrete with a slump of 7.5 cm and air content of 5.1% was used for comparison.

All materials except water and the admixture were charged into a pan-type mixer with a capacity of 100 liters and dry-mixed. Water and the admixture were then added and thoroughly mixed. The mixed sample was placed in the specified

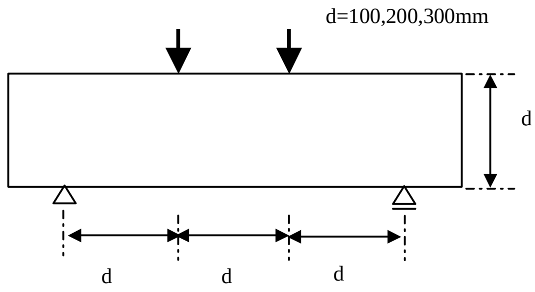

Figure 6. Test setup (specimen depth series)

Table 3. Specimen size (specimen depth series)

100mm depth specimen	100x100x400
200mm depth specimen	200x100x800
300mm depth specimen	300x100x1200

First loading	1600mm length specimen (Moment span: 400mm, Loading span: 1200mm)
Second loading	800mm length specimen (Approximately) (Moment span: 200mm, Loading span: 600mm)
Third loading	400 mm length specimen (Approximately) (Moment span: 100mm, Loading span: 400mm)

Figure 7. Experimental procedures (specimen length series)

molds in two layers, with compacting by a tamping rod (rod end size: 35 x 35mm).

All specimens were demolded 3 days after placing, and wet-cured in a thermostatic room at 20°C until loading at an age of 28 days. The loading was applied in the direction at perpendicular to the placing direction.

3.2 Specimen size and loading method

3.2.1 Outline

In this experiment, two kinds of tests were conducted:

- Bending tests on different specimen depth, and
- Bending tests on different specimen length

Details of these tests are described in next section. Specimens (100 mm in diameter and 200 mm in length) were also fabricated. The total void ratio of porous concrete was measured using the specimens in accordance with "The Test Method for Void Ratio of Porous Concrete (draft)" specified by Japan Concrete Institute Research Committee on Eco-concrete.

3.2.2 Specimen depth series

In order to investigate the effects of the specimen depth on the calculated flexural strength, four-point bending tests were conducted using the beam specimens having depths of 100, 200 and 300mm, as shown in Table 3. Specimen length was equal to four times of specimen depth, and specimen width was 100mm, which is constant value. Moment span lengths in the tests equal to specimen depths. Only a load was measured by a loadcell.

3.2.3 Specimen length series

In order to investigate the effect of specimen length on the flexural strength, three beam specimens measuring 100x100x1600mm were fabricated for each concrete. Four-point bending tests with a moment span of 400 mm were conducted (first loading). One of the two separated specimens (approximately 800 mm in length) obtained after first loading was subjected to four-point bending tests with a moment span of 200 mm (second loading). One of the two separated specimens resulting from the loading test (approximately 400

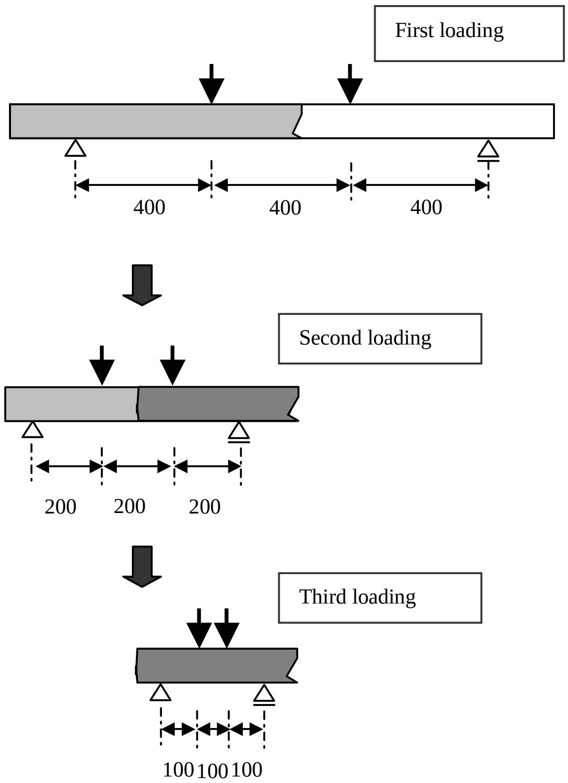

Figure 8. Test setup (specimen length series)

Figure 9. Specimen after the tests

mm in length) was again subjected to four-point loading with a moment span of 100 mm (third loading). In this manner, three loading tests were conducted using the same specimen initially 1600 mm long to calculate the flexural strength for each length. Figure 9 shows typical specimens after the tests. Slightly damage (micro cracks) due to repeated loading on the same specimens might affect the test results. However, the effects might be less significant than those of the variability of the production process, such as the degree of compacting, on the mechanical properties of the porous concrete specimens. When calculating the flexural strength, the moments by loading apparatus and the deadweight of the specimens were incorporated.

4 RESULTS AND DISCUSSION

4.1 Void ratio and compressive strength

Table 4 gives the measured void ratio of the porous concrete and the compressive strength of all concretes. The compressive strength of porous concretes ranged between 10 and 17MPa, whereas that of ordinary concrete was approximately 37MPa.

4.2 Size effect regarding specimen depth (specimen depth series)

Table 5 and Fig. 10 show the flexural strength of porous concrete. Experimental results in the reference (Ando et al. 1995) and analytical results using tension softening relation of ordinary concrete (Tensile strength: 3.0MPa, Fracture energy: 150N/m) are also shown in Fig. 10. The obtained results in this experiment were similar with the results of the reference. The flexural strength of the 100mm depth specimens was as large as that of 200mm depth ones in all porous concrete series. In ordinary concrete, the strength of the 100mm depth specimens was, however, largest in all specimen sizes. It seems that cross section area of porous concrete, which contributes to stress transfer in both compression and tension side, is smaller than that of ordinary concrete, because the outside surface of the porous concrete specimen has large amount of voids due to significant wall-effects. However, it seems that the wall-effects decrease with increasing of specimen size. Both strengths of 100mm depth and 200mm depth specimens were larger than that of 300mm depth specimen. The dot lines calculated by the least squares method show that the flexural strength of the porous concrete inverses approximately 1/4

Table 4. Total void ratio and compressive strength of porous concrete

Test series	Specimen series	Total void ratio (%)	Compressive strength (MPa)
Specimen depth	Porous HS	17.6	15.9
Specimen length	Porous L	26.1	14.2
	Porous S	24.9	10.9
	Porous HS	19.0	16.9
	Ordinary concrete	-	37.2

Table 5. Flexural strength of porous concrete

(Unit: MPa)

100mm depth specimens	200mm depth specimens	300mm depth specimens
4.34 (0.37)	4.26 (0.14)	3.97 (0.41)

Standard deviations are shown in parenthesis

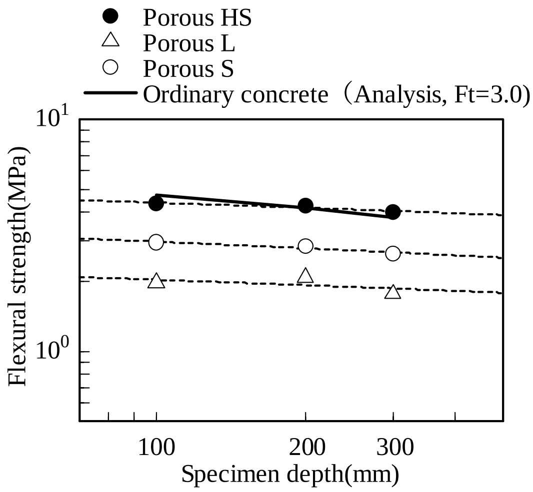

Figure 10. Flexural strength (specimen depth series)

power in all series. Regarding the specimen depth, the size effect on flexural strength of porous concrete was similar to that of ordinary concrete.

4.3 Size effect regarding specimen length (specimen length series)

Table 6 shows the flexural strength of specimens with different lengths calculated from the results of four-point bending tests. Figure 11 indicates the normalized strengths that are normalized with respect to the flexural strength of 400mm length specimens.

Table 6. Flexural strength

Specimen series	Flexural strength (MPa)		
	1600mm length specimen	800mm length specimen	400mm length specimen
Porous L	1.76 (0.07)	1.91 (0.08)	1.91 (0.17)
Porous S	1.95 (0.08)	2.24 (0.11)	2.09 (0.10)
Porous HS	3.37 (0.24)	4.05 (0.15)	3.91 (0.34)
Ordinary concrete	4.94 (0.09)	4.59 (0.06)	4.94 (0.24)

Standard deviations are shown in parenthesis

Regarding the porous concrete, the flexural strength of 800mm length specimens exceeded that of 400mm length specimens, but the reason is unknown at the present stage. However, the flexural strength of 1600mm length specimens tended to be slightly lower than those of 400mm and 800mm length specimens. This tendency was particularly evident with porous HS. In this study, the size effect of specimen length was not clearly observed in ordinary concrete. It seems that the size effect observed in porous concrete can be attributed to a mechanism in which cracks in porous concrete develop through the weakest portions within a specimen. As the specimen length (moment span length for loading) increases, the amount of voids, i.e., potential defects, increases. The obtained data exhibit that slight size effect on the flexural strength of porous concrete with increasing of specimen length. Further experimental data and discussions are, however, needed.

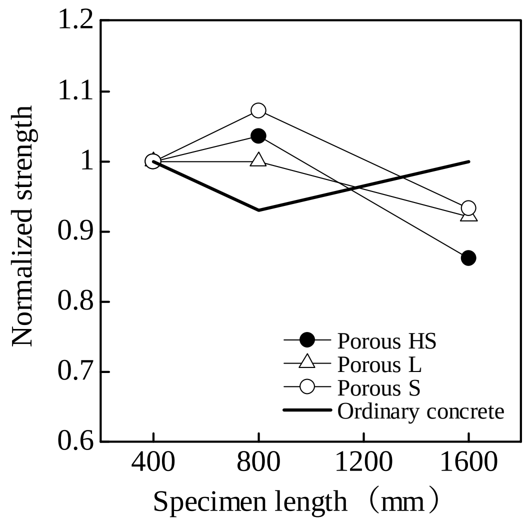

Figure 11. Flexural strength (specimen length series)

5 CONCLUSIONS

The present experiments led to the following conclusions:

(1) Regarding the specimen depth, the flexural strength of the porous concrete inverses approximately 1/4 power in all series. The size effect on flexural strength of porous concrete was similar to that of ordinary concrete.

(2) The obtained data exhibit that the size effect on the flexural strength of porous concrete with increasing of specimen length was larger than that of ordinary concrete. Further experimental data and discussions are, however, needed.

6 REFERENCES

Ando, T., Kurihara, N., Uchida, Y. & Rokugo, K., 1995, Flexural failure behavior of porous concrete, Transaction of the Japan Concrete Institute, Vol. 17, pp.69-76

Bažant, Z. P. & Planas, J., 1998, Fracture and size effect in concrete and other quasibrittle materials, CRC Press

Carpinteri, A., 1996, Strength and toughness in disordered materials: complete and incomplete similarity, Size-scale effects in the failure mechanisms of materials and structures, E&FN SPON, pp.3-26

Koide, H. & Tomon, M., 1997, Size effect on the length of concrete beams under bending moment, Proc. of the Japan Concrete Institute, Vol. 19, No. 1, pp.559-564

Kunieda, M., 1999, Surface properties and performance of concrete members, Dr. Eng. Thesis, Gifu University, Japan, pp.143-161

Tamai, M., Mizuguchi, H., Hatanaka, S., Katahira, H., Nakazawa, T., Yanagibashi, K. & Kunieda, M., 2003, Design, construction and recent applications of porous concrete in Japan, Proc. of 28th Conference on Our World in Concrete & Structures, pp.121-130